Precambrian in the external zones o f the Variscides: central and northern parts o f the Armorican Massif

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Chapter 1

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Contents

Cadomian tectonic effects appear relatively minor and are seen to diminish in importance as one goes towards the south and east away from the Domnonean 'Cordillera' (ridge). The deformation style of these external parts of the Cadomian chain is characterized by a lack of cleavage and a development of synsedimentary breccias and superficial recumbent folds produced by local sliding over an unknown basement.

Both the Brioverian and its Palaeozoic cover are actively affected by Hercynian deformation; in fact, most of the schistosity developed in the Brioverian of Central Brittany relates to Variscan orogenesis.

The southern limit of the domain is marked by the northern branch of the South Armorican Shear Zone, which is itself guided by the Lanvaux granitic-gneiss belt. Intrusives along this axis have Ordovician and Silurian ages and appear as the first signs of crustal distension that, further south, characterizes the early stages in the evolution of the Ligerian active margin.

1.1 PRECAMBRIAN IN THE DOMNONEAN DOMAIN: THE TRÉGOR MASSIF OF NORTH BRITTANY

Bernard Auvray
(Translated by M. S. N. Carpenter)

Of all the different palaeogeographic and structural provinces which make up the Armorican massif, it is only in the Domnonean domain that Precambrian terrains are well preserved with their original characteristics (see Fig. 1).

Within this domain several core-areas and massifs have been shown to exist, separated from each other by narrow tectonic belts which have taken up most of the deformation during the Hercynian orogeny (Cogné, 1974). In fact, these 'mobile belts' were already active at the end of the Cadomian orogeny since they delimit graben structures which correspond to Palaeozoic sedimentary basins.

Our geological understanding of the different core-areas in the Domnonean domain is very patchy, with many stratigraphic, petrological, structural, and geochronological problems waiting to be answered. This is particularly the case for the Pentevrian massif, where probably the most complete Precambrian sequence is exposed but where reconnaissance studies and characterization of the rock types are perhaps the most poorly developed. For this reason, even if the Pentevrian was first defined in this massif (Cogné, 1959) and even if the existence of an ancient basement is very likely, there is no evidence so far for rocks older than 1000 Ma. This is in contrast with the situation further north in the Trégor massif and in the Channel Islands (Fig. 1).

In fact, the only massif of the Domnonean domain that has been intensively studied is the Trégor massif (Auvray, 1979). However, it is not possible here to observe the full sequence of Precambrian series as, for example, further south in the Baie de St Brieuc where lower Brioverian volcano-sedimentary formations are exposed (Cesson-Lanvollon). Such formations are not represented in the Trégor, except perhaps towards the western limit of the area (l'Armorique) where some metabasic rocks associated with metasediments could possibly be assigned to the lower Brioverian. This interpretation is still controversial and agreement has not been reached between different workers (Auvray, 1979; Autran *et al.*, 1979). Whatever the correct interpretation might be, the present study is concerned with a description of the Precambrian of the Domnonean domain within the confines of the Trégor massif. This is because most of the information necessary to establish a stratigraphic sequence in the midst of the Precambrian of Armorica comes from the Trégor. In addition, this information will prove useful in constructing a model of geodynamic evolution before the Palaeozoic for the northern Armorican massif.

The Trégor Massif—General Framework

The massif is a geological unit of limited size (*ca.* 40 km × 15 km) having a rectangular outcrop and situated in the most northerly part of Brittany. It is bounded on three sides by the Channel, giving an indented coastline which aids geological observations. The southern limit of the massif corresponds to the trace of a major E-W fault (Fig. 2; F_2) known as the Trégorrois fault. This fault is particularly apparent in the east of the Trégor, where its displacement during the Hercynian has juxtaposed Brioverian rocks with Palaeozoic formations (Cambro-Ordovician Red Beds; Auvray *et al.*, 1980a).

Geologically speaking, the Trégor can be divided into two sub-areas separated by another important E-W fault running parallel to the Trégorrois fault; this fault is known as the Tréguier-Lézardrieux fault (see Fig. 2; F_1).

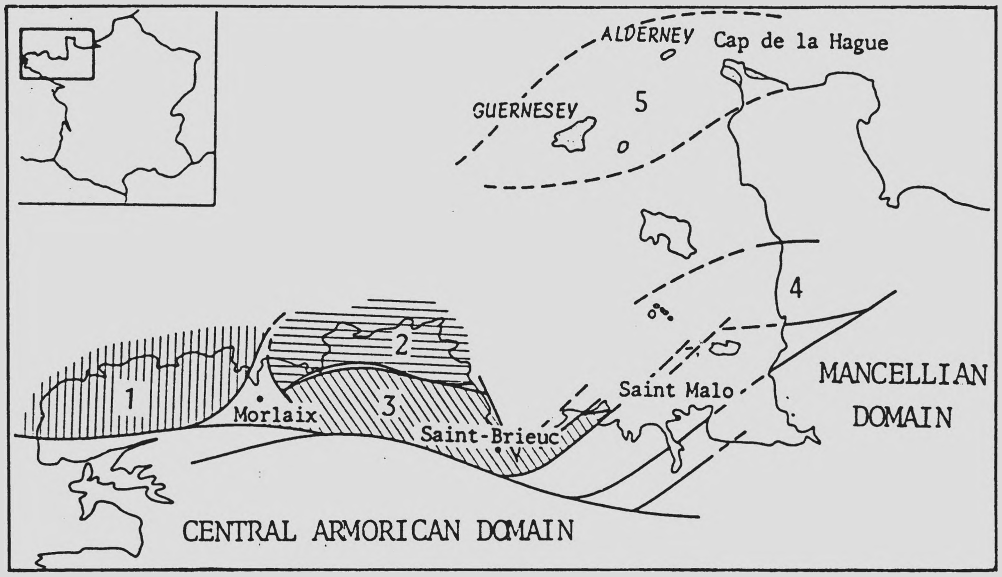

Fig. 1. Sketch map of the Domnonean domain. The different massifs or core-areas of Precambrian age are separated by Hercynian 'mobile belts'. 1—The Léon Massif; 2—The Trégor Massif; 3—The Penthièvre Massif; 4—The Lower Normandy Massif; 5—The Channel Islands Massif (after Cogné, 1974; in Vidal *et al.*, 1981)

The northern sub-area is composed essentially of plutonic crystalline rocks and metamorphic schists and gneisses, the greater part of the outcrop being occupied by the North Trégor Batholith dated at 600–650 Ma (Adams, 1967; Auvray and Vidal, 1973; Vidal, 1976; Auvray, 1979). Fragments of a Lower Proterozoic basement are to be found as xenoliths/enclaves within the batholith (Auvray, Charlot, and Vidal, 1980); the only evidence for Palaeozoic phenomena in the area is also recorded as various magmatic episodes (dolerite dyke swarms and plutonic activity in the form of monzonitic and

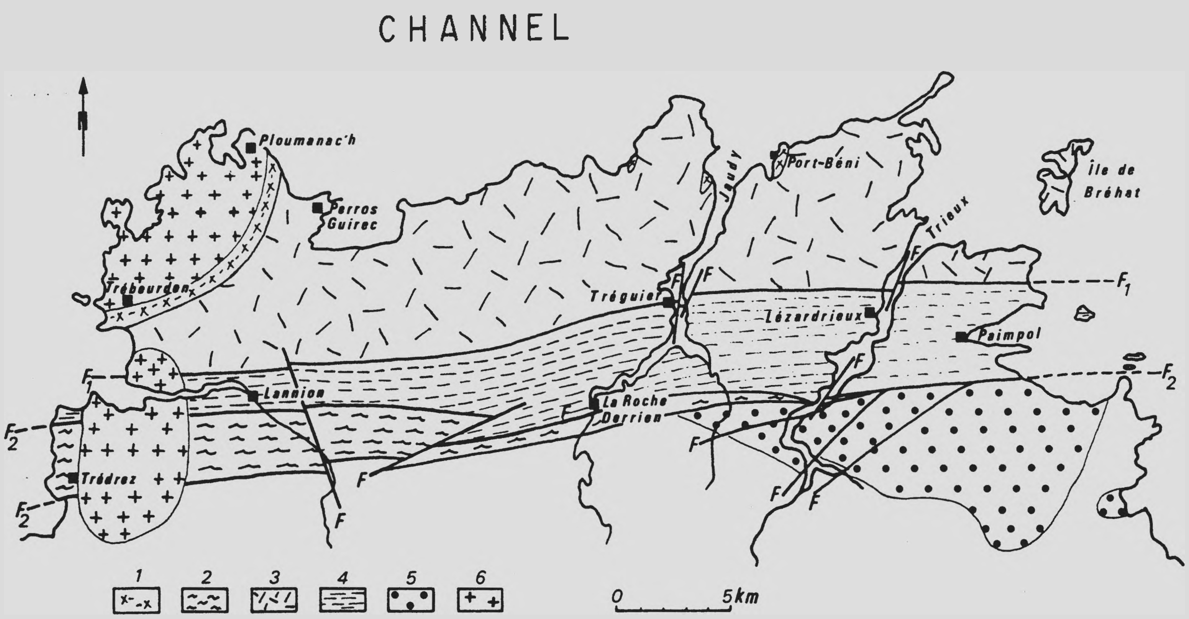

Fig. 2. Geological and structural sketch map showing the major faults affecting the Trégor Massif. 1—Ancient basement gneisses; 2—Volcano-sedimentary formation of l'Armorique-Trédrez; 3—The North Trégor Batholith; 4—Volcanics and sediments of the southern sub-area of the Trégor; 5—Palaeozoic Red Bed formations (Bréhec-Plouézec-Plourivo); 6—Hercynian granites (in Auvray, 1979)

	Radiometric age in Ma	
PALEOZOIC		Late-Stage N-S faulting
	300	Emplacement of Ploumanac'h granitic complex
	320-310	Emplacement of Tredrez Granite Mouvement along major E-W fault Emplacement of Plouaret-Begard batholith
	350-440	Doleritic dyke swarms
	470	Deposition of Red Bed formations with associated volcanism
UPPER PROTEROZOIC (Brioverian)	550-540	Alkali-granitic and rhyolitic igneous activity (granites, microgranites and ignimbrites)
	600-580	Dioritic intrusions (Keralain-Taurel)
	CADOMIAN II DEFORMATION	
	640-600	Deposition of Roche-Derrien sandstone and shale series (≡Binic series) Eruption of Paimpol spilites Deposition of Treguier keratophyric tuffs (Locquirec tuffs as well) Basal conglomerates with granodiorite clasts Emplacement for Perros-Guirec-Bréhat batholith(granites and granodiorites)
	CADOMIAN I DEFORMATION	
	< 1,000	Deposition of St Efflam greywacke formation L'Armorique-Trédrez volcano-sedimentary series (≡Lanvollon volcano-sedimentary formation)
Lower to Mid-Proterozoic	> 1,800	Basement gneisses and orthogneisses (Trébeurden and Port-Beni Gneisses) ≡Icartian or Pentevrian. (?) plutonic activity at 2,000 and 1,800 Ma

Fig. 3. Chronology of events rcorded in the Trégor and adjoining areas (Petit Trégor and Baie de Saint Brieuc) (after Auvray, 1979)

sub-alkaline granites; e.g. Trédrez granite, Ploumanac'h ring complex described by Auvray, 1979 and Barrière, 1977 respectively).

The southern sub-area is made up of Upper Brioverian volcano-sedimentary formations with the following stratigraphic succession (from base to top):

— Tréguier keratophyric tuffs
— Paimpol spilites
— Roche-Derrien sediments (equivalent to the Binic series further south).

Rare gabbro–dioritic intrusions of limited size are to be found in this southern half of the Trégor. These intrusions are the local equivalents of much larger granodioritic and dioritic intrusions found elsewhere in the Armorican Massif which have been dated from St Quay–Portrieux (Vidal *et al.*, 1971), Plévenon–Fort La Latte (Vidal *et al.*, 1974) and in the Mancellian domain of Lower Normandy (Jonin and Vidal, 1975).

A magmatic episode common to both sub-areas of the Trégor occurred during latest Proterozoic times (*ca.* 550 Ma ago) and is observed as ignimbrite flows in the south and as a microgranite/granite intrusive event in the north (Auvray and Vidal, 1973; Vidal, 1976; Auvray, 1975, 1982). This event appears to mark the end of Precambrian times in the region (for a recent definition of the Precambrian–Cambrian limit see data of Odin, 1982 and Odin and Gale, 1982).

A compilation of all data obtained on the Trégor Massif, including both geological and radiometric observations, has led to the drawing-up of a stratigraphic column calibrated by geochronological results (see Fig. 3).

Description of the Different Lithological Units

The following units (or rock series) will be described in the order given below:

A—Formations of the ancient basement
B—The North Trégor calc-alkaline batholith
C—Volcano-sedimentary formations of the southern Trégor
D—Mancellian-type gabbro–dioritic intrusives
E—End Precambrian alkali-granite and rhyolite suite.

A—Formations of the ancient basement

Included under this heading are a series of metamorphic schists and gneisses known for a long time in the Trégor as the Port-Béni gneisses and the Trébeurden gneisses (Barrois, 1908a, 1908b). The Port-Béni gneisses occur as 10–100 m scale enclaves included within the body of the North Trégor Batholith, whereas the Trébeurden gneisses make up a narrow, continuous screen between the North Trégor Batholith and the late Hercynian Ploumanac'h intrusive complex (Vidal, 1976; Barrière, 1977). The Trébeurden gneisses, however, are seen to extend towards the southwest (near Locquirec) where they can be correlated with the Morguinen gneisses and the Moulin de la Rive gneisses (Verdier, 1968). All these different fragments of gneissic basement taken together constitute a NE–SW oriented belt which seems to mark out the northern limit of the Armorican Massif. This belt runs from the Moulin de la Rive gneisses in the southwest, through the Icart gneisses of the Channel Islands to the Cap de la Hague gneisses in the northern part of the Cotentin peninsula (Adams, 1967, 1976; Roach, 1966, 1977; Leutwein *et al.*, 1973; Cogné, 1959, 1962, 1974; Auvray and Vidal, 1973; Calvez and Vidal, 1978; Auvray, Charlot, and Vidal, 1980; Vidal *et al.*, 1981). The age of this metamorphic basement is now well known as being between 1.8–2.0 Ga (Adams, 1967; Calvez and Vidal, 1978; Auvray, Charlot and Vidal, 1980) (see Fig. 4). Thus these ancient basement formations belong to the Lower Proterozoic (Pentevrian of Cogné, 1959) and as such represent the oldest known relicts within the Variscides of Western Europe (Auvray, 1979).

In terms of lithology, two main groups can be distinguished amongst the gneisses:

Banded gneisses The bands vary in thickness from *ca* 10 cm (Port-Béni) to 1 m or more (Trébeurden), making up a suite of differentiated rock-types as follows:
(a) light-coloured, biotite-bearing gneisses of granodiorite composition
(b) light-coloured gneisses of rhyolitic composition containing euhedral quartz of volcanic origin
(c) light-coloured leptynites (microcline, albite, and quartz making up more than 95 per cent of the rock), also of rhyolitic composition
(d) Dark-coloured, fine-grained amphibolites containing essential hornblende, biotite, plagioclase An_{30-45} and quartz; the whole-rock composition is basaltic
(e) Dark-coloured mica schists containing biotite, plagioclase An_{20-40} and quartz. This paragenesis is rather rare.

Augen-gneisses These are, in fact, foliated granites (orthogneisses) whose intrusive relationship into the banded gneisses can sometimes be demonstrated. In these gneisses, there are cm-scale pink or white porphyroblasts (orthoclase or perthitic microcline) with recrystallization trails wrapped around external reaction rims (coronas); the cores of these K-feldspar augen may be the relicts of original igneous phenocrysts. The matrix has a granoblastic texture

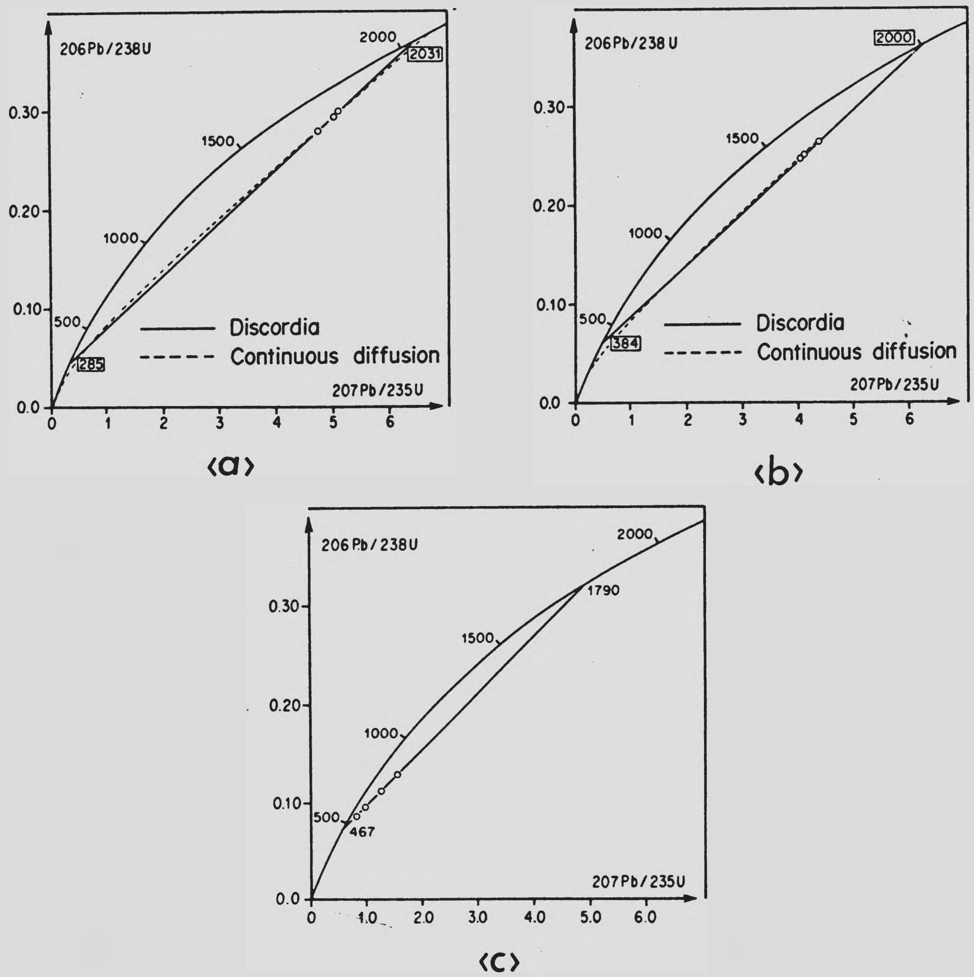

Fig. 4. U/Pb zircon ages obtained on ancient basement in the Trégor. Concordia calibrated in 500 Ma intervals, intercept ages in boxes. a: Trébeurden Orthogneiss; b: Morguignen Orthogneiss; c: Port-Béni Orthogneiss (in Auvray, Charlot, and Vidal, 1980)

and contains essential andesine (An_{30}), perthitic microcline, quartz and biotite with accessory hornblende, epidote, apatite, zircon, and opaque minerals. These orthogneisses have compositions varying between granodioritic and monzonitic.

Such fragments of gneissic basement, often scattered and of rather small size, do not enable us to reconstruct the original structural relationships of the formations concerned; neither do they help establish the precise metamorphic facies or deformation-crystallization histories, due to the absence of diagnostic mineral paragenesis. Nevertheless, it appears that the main episode of metamorphism occurred during an isoclinal phase of folding which led to the dominant foliation observed in these gneisses. The metamorphism is intermediate in grade (medium pressure sequence or Barrovian type), only rarely attaining the conditions necessary for partial melting as observed in the Port-Béni gneiss where there is some evidence for incipient migmatization (pegmatoid mobilizates, metatexites).

Apart from the mica schists, all the ancient basement gneisses seem to be of igneous, or sometimes mixed volcano-sedimentary (tuffaceous), origin; this is shown not only by petrography but also by chemical composition (see Fig. 5). Compositions varying from basaltic (amphibolites) to rhyolitic (gneisses with euhedral quartz, leptynites) allow us to recognize a calc-alkaline igneous suite in which the monzonitic/granodioritic orthogneisses have an integral part.

It should be pointed out that the radiometric ages obtained have been determined from orthogneiss samples and that the age is thus an emplacement age. Since these orthogneisses have an intrusive

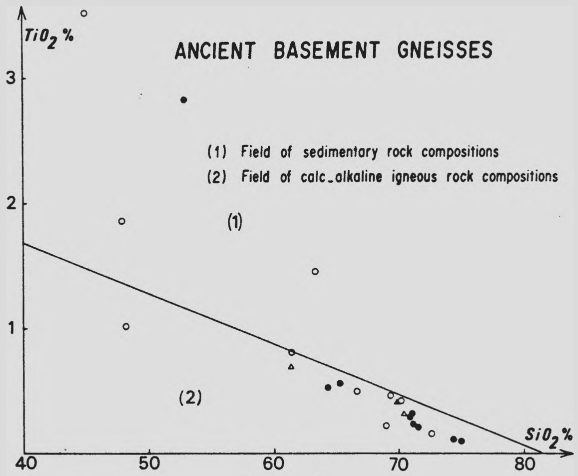

Fig. 5. Ancient basement gneisses of the Trégor plotted on a TiO_2 vs SiO_2 diagram (Tarney, 1976). ●, ▲ : gneisses, orthogneisses—Trébeurden; ○, △ : gneisses, orthogneisses—Port-Béni (in Auvray, 1979)

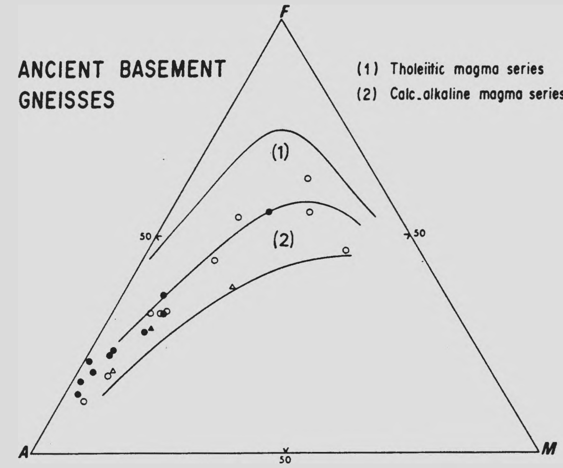

Fig. 6. Ancient basement gneisses of the Trégor plotted on an AFM diagram, some symbols as for Fig. 5. (in Auvray, 1979)

origin, it would seem that the country rocks (banded gneisses) are probably older than 2 Ga. On the other hand, no constraints can be placed on the real age of metamorphism because there is no evidence on whether the metamorphism followed shortly after or long after plutonism.

Finally, it should be added that contact metamorphism (recrystallization in thermal aureoles) of variable intensity is observed in the basement gneisses near later granodiorites and near the Ploumanac'h granite (e.g. occurrence of sillimanite at the contact; Barrière, 1977; Auvray, 1979). Always, these contact phenomena are very limited in extent.

B—The North Trégor Batholith

The North Trégor Batholith is a complex massif (see Figs. 7, 8, and 9) made up from several different phases of magmatic activity whose relative timing is difficult to determine. In spite of this difficulty, field relationships have made it possible to recognize the following succession (Auvray, 1979), starting from the oldest:

—The Castel-Meur quartz-diorite
—The Talberg granodiorite and the Pleubian microgranodiorite
—The Pomelin–Bréhat monzonite granite and the Launay monzonitic microgranite
—The Port-Blanc monzonitic granite.

Throughout the massif, rocks show good examples of plutonic textures (equant grains) which remain completely unaffected by deformation. The only evidence for the influence of tectonic events is seen in narrow cm-scale shear zones oriented 70° NE to 80° NE filled with quartz and epidote and a system of N–S oriented faults with horizontal displacements of no more than a few metres. This latter phase of brittle deformation is undoubtedly Hercynian, whereas the shears could be either end Cadomian or Hercynian in age.

Otherwise, all rock types contain fine-grained enclaves (Didier, 1973) of dioritic or granitic composition which vary in abundance according to the lithology under consideration. Regardless of lithology, vein networks are poorly developed but can appear as rare aplitic veins (Pomelin–Bréhat type of Port-Blanc type).

The entire batholith is cut by several generations of late veins or dykes. This group includes microgranites, dolerites and lamphrophyres much younger than the batholith (end-Precambrian–Palaeozoic) (Auvray, 1975; Auvray, 1979) and without any genetic link to it.

The Castel-Meur quartz-diorite This rock type only occurs as blocks of variable size (cm-scale to 10 m) within Pleubian-type microgranodiorites (see Fig. 7). The well defined, angular outlines of these enclaves, lacking any sign of mixing with the granodioritic magma, indicate that the diorite was completely crystallized and cooled off before it was injected by the granodioritic magma. Blocks are sometimes so abundant in the granodiorite that the outcrop begins to resemble a magmatic breccia (agmatite).

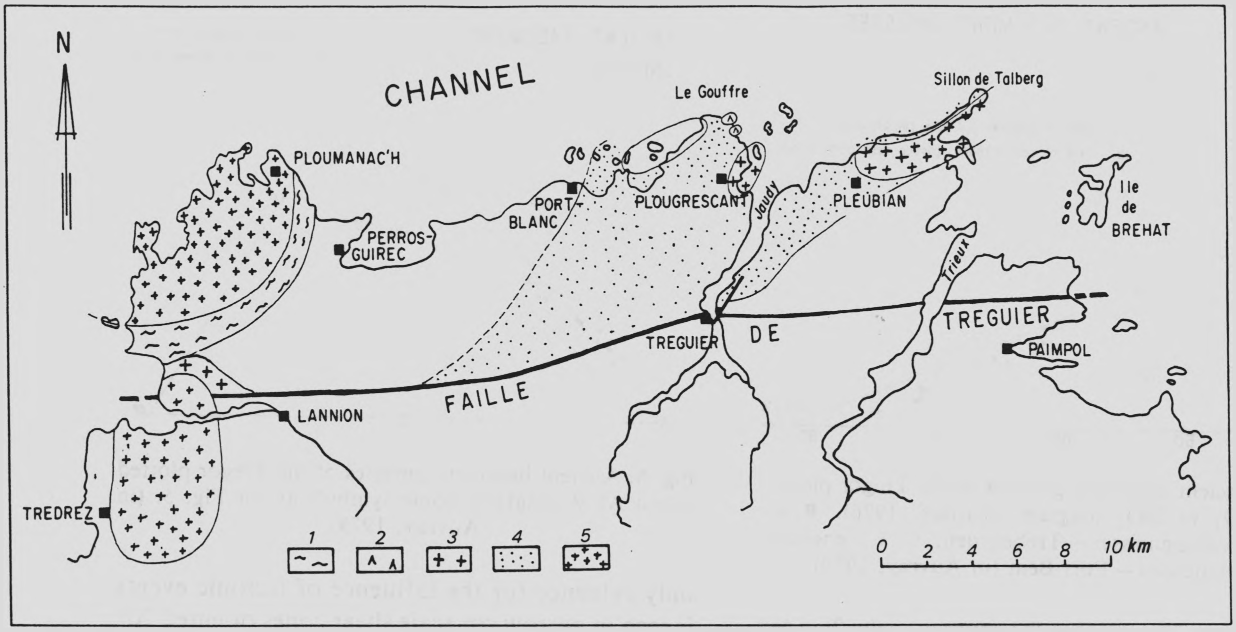

Fig. 7. Sketch map showing outcrop of granodioritic and dioritic rocks in the northern sub-area of the Trégor. 1—Trébeurden gneisses; 2—The Castel-Meur diorite; 3—The Talbert granodiorite; 4—The Pleubian microgranodiorite; 5—Hercynian granites (in Auvray, 1979)

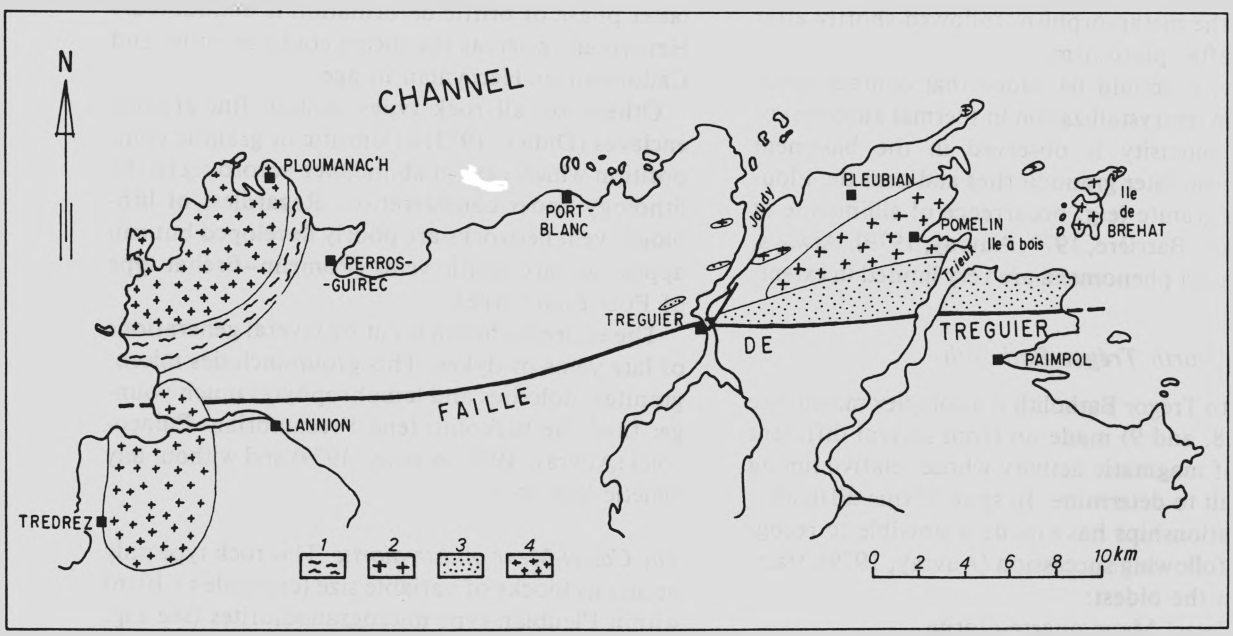

Fig. 8. Sketch map showing outcrop of monzogranitic rocks in the northern sub-area of the Trégor. 1—Trebeurden gneisses; 2—The Pomelin-Bréhat granite; 3—The Launay microgranite; 4—Hercynian granites (in Auvray, 1979)

The fact that diorite enclaves predate the microgranodiorites is confirmed by petrographic study which shows the following sequence of parageneses with time:

Primary magmatic paragenesis: medium grain-size equigranular texture containing andesine (An_{45}), green hornblende, biotite, and accessory quartz.

Secondary paragenesis: fine-grained, hornfels texture containing andesine (An_{35-45}), actinolite, biotite, quartz, and opaque minerals. Chlorite and epidote are commonly developed in these

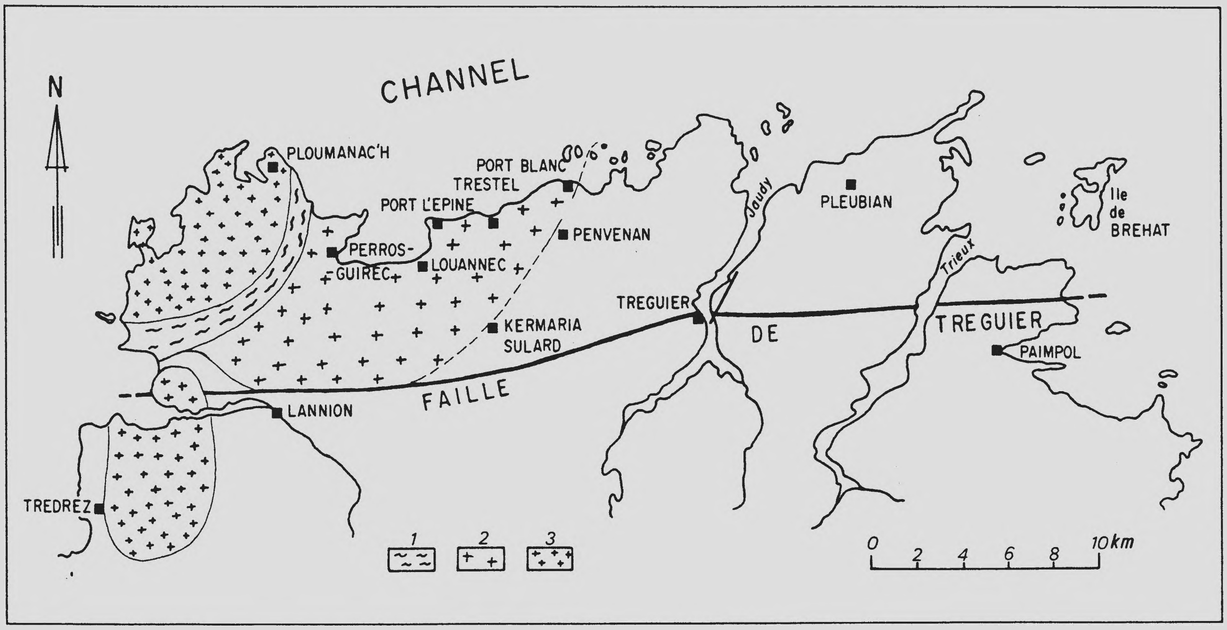

Fig. 9. Sketch map showing outcrop of Port-Blanc type granite in the northern sub-area of the Trégor. 1—Trebeurden gneisses; 2—The Port-Blanc granite; 3—Hercynian granites; (in Auvray, 1979)

diorites as destabilization products derived from the primary and secondary parageneses.

The average composition of the Castel-Meur diorite is given in Table 1 (Col. 1).

The Talberg granodiorite and the Pleubian micro-granodiorite These two varieties occupy the central part of the batholith (see Fig. 7) and are closely associated with each other, the transition between the two being often gradual and diffuse. The emplacement of these granodiorites must have occurred shortly before the monzonitic granites (see section below) as witnesses the occurrence of enclaves with diffuse scalloped borders in, for example, the Launay microgranite.

These two varieties of granodiorite differ only in texture; one being coarse grained and the other fine grained with phenocrysts mainly of plagioclase and hornblende. In both cases, the mineral assemblage is: plagioclase (An_{17-35}), green hornblende, biotite, quartz, perthitic orthoclase, opaque minerals, epidote group minerals (including allanite), sphene, apatite, and zircon. Minerals derived from alteration (chlorite, epidote, sericite, actinolite, and leucoxene) are also present. Generally speaking, the most abundant dark mineral is hornblende which sometimes contains inclusions of relict clinopyroxene (augite). Micropegmatitic intergrowths of quartz and alkali feldspar are common in the mesostasis of some fine-grained varieties of granodiorite.

The chemical composition of these two rock types is given in Table 1, (col. 2 and 3). The composition of these plutonic igneous rocks is clearly granodioritic, with the fine-grained varieties being noticeably more differentiated than the coarse varieties.

The Pomelin–Bréhat monzonitic granite and the Launay monzonitic microgranite As with the previously discussed granodiorites, these two varieties of monzonitic rocks are closely related to each other with gradual and diffuse transitions from one to the other. They occupy the eastern part of the batholith, and the difference between them is, again, entirely textural (medium grained in one case and fine grained with phenocrysts of oligoclase-albite, hornblende, biotite and quartz in the other).

In both cases, light-coloured minerals make up more than 80 per cent of the whole (leucocratic) rock and biotite is generally more abundant than hornblende. Plagioclase is often zoned (An_{5-30}) and always more abundant in the mode than orthoclase (35 per cent modal plagioclase *cf.* 25 per cent modal orthoclase). Quartz is abundant around 25 per cent modal. The accessory minerals are: opaques, apatite, zircon, and allanite. Epidote, chlorite, and sericite are the most common alteration products from primary parageneses.

Table 1. Chemical compositions of various types of granitoid composing the 'Batholite nord-trégorrois', mean values (n = number of data) (after Auvray, 1979)

	1		2		3		4		5		6	
	n = 3		n = 7		n = 19		n = 10		n = 10		n = 7	
	$\bar{m}$	σ	$\bar{m}$	σ	$\bar{m}$	σ	$\bar{m}$	σ	$\bar{m}$	σ	$\bar{m}$	σ
SiO_2	54.93	1.82	59.97	5.81	64.25	4.72	67.39	2.18	66.40	1.18	70.41	1.06
Al_2O_3	13.90	2.53	16.66	0.89	16.24	1.05	15.02	0.86	16.20	0.44	13.89	0.49
Fe_2O_3*	8.32	0.29	6.39	2.11	4.92	1.45	4.00	0.65	4.01	0.47	3.45	0.35
MnO	0.13	0.006	0.09	0.02	0.08	0.04	0.06	0.009	0.06	0.01	0.06	0.007
MgO	8.12	4.12	2.37	1.43	1.55	0.79	1.05	0.69	1.21	0.22	0.79	0.13
CaO	6.62	0.93	4.62	1.72	3.86	1.61	2.31	0.50	2.17	0.69	2.20	0.50
Na_2O	2.52	0.72	3.90	0.64	3.66	0.31	4.26	0.48	4.35	0.37	3.55	0.10
K_2O	1.59	0.62	2.43	0.75	3.03	0.70	3.61	0.25	3.74	0.41	3.46	0.22
TiO_2	0.55	0.35	0.84	0.39	0.59	0.30	0.40	0.07	0.42	0.06	0.36	0.05
H_2O^+	1.99	0.23	1.66	0.47	1.37	0.35	1.03	0.63	1.13	0.31	1.03	0.14
H_2O^-	0.23	0.08	0.19	0.06	0.15	0.06	0.054	0.51	0.23	0.14	0.14	0.01

The average composition of the two textural types is given in Table 1 (col. 4 and 5), from which the close similarity of these rocks with monzonitic granites can be demonstrated.

The Port-Blanc monzonitic granite This rock type occupies the western part of the batholith (see Fig. 9). From cartographic evidence, it appears to cut the granodiorites, but the contacts between the different units are never observed in the field. The Port-Blanc monzonitic granite can be distinguished from all other granites in the Trégor by its coarser grain size and great abundance of quartz (30–35 per cent modal). The monzonitic character of this rock type is clearly indicated, once again, by feldspar mineralogy and modal composition (plagioclase $An_{12} \simeq 34$ per cent of the mode; intermediate microcline $\simeq 27$ per cent of the mode). Hence, this granite can be termed leucocratic; biotite is the dominant dark mineral, making up to 6–7 per cent of the rock, whereas hornblende rarely exceeds 1 per cent. Apatite, zircon, magnetite, and allanite are the most common accessory minerals; chlorite, epidote, and sphene are derived from the alteration of primary parageneses.

The chemical composition of this granite type is very homogeneous (Table 1, col. 6), showing very high silica contents ($SiO_2 > 70$ per cent) and about equal contents of Na_2O and K_2O as would be expected in rocks of monzonitic character.

All the different types of plutonic rocks represented in the North Trégor Batholith taken together make up a good example of a calc-alkaline igneous suite (see Fig. 10). Differentiation of the suite appears to have occurred by fractional crystallization (Auvray, 1979), though geochemical data seem to indicate the existence of two primary magmas of similar but different composition. Each of these initial liquids probably underwent fractional crystallization to yield the suite of rock types as observed today (Auvray, 1979; Graviou, in preparation 1983).

We should also bear in mind that the age of this batholith has not yet been determined with precision. Attempts to obtain a Rb–Sr whole-rock isochron (Vidal, 1976) have yielded no result. Recent U–Pb zircon studies should help in dating the emplacement of the batholith (Brioverian; Graviou, personal communication, 1982).

Field relations seem to suggest that plutonic activity in the northern Trégor preceded Brioverian volcanism in the south (see next chapter) since spilitic and keratophyric dykes are seen to cut batholith rocks. In fact, these two manifestations

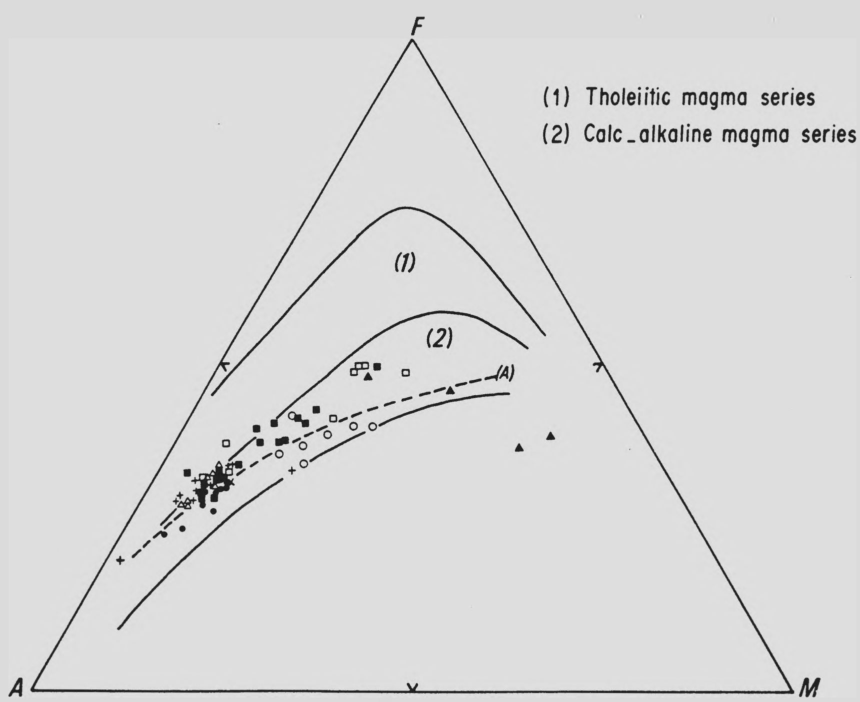

Fig. 10. Calc-alkaline differentiation trend in the North Trégor Batholith as shown by the AFM diagram. A: differentiation trend exhibited by the Californian Batholith (after Carmichael *et al.*, 1974). (in Auvray, 1979)

of igneous activity are nearly synchronous; plutonic emplacement episodes alternated with outbursts of volcanic activity. The geochemical characteristics of these two magmatic suites are very similar (calc-alkaline) and show that they are both related to the same geodynamic context as discussed below.

C — Volcano-sedimentary formations in the southern Trégor

The Tréguier Keratophyres These volcanics, which are assigned to the base of the Upper Brioverian, occupy a broad band of outcrops from Paimpol in the east to Lannion (and beyond Locquirec) in the west (see Fig. 11). The thickness of this formation is about 1000 m.

The formation contains mostly violet to green coloured pyroclastic rocks (tuffs) with occasional intercalations of apparently lenticular lava units. In such fine-grained crystalline rocks, the only visible phenocrysts are mm-scale crystals, sometimes broken, of plagioclase (the most abundant), retromorphosed amphibole, rare quartz, and K-feldspar. Mineral parageneses are as follows:

— Phenocryst assemblage: plagioclase (An_{8-15}), hornblende, biotite, orthoclase, and quartz.
— Groundmass: quartz, sericitic muscovite, apatite, granular opaque phase, and zircon.

Amphibole is nearly always altered to a mixture of chlorite, epidote, opaques, quartz, sericite, leucoxene, and calcite which pseudomorphs the original euhedral grains.

Table 2 shows the range of composition demonstrated by these volcanics and shows that they correspond broadly to the definition of keratophyres. The relative variation of Na_2O and K_2O contents in these rocks ($Na_2O + K_2O \simeq 8$ per cent) falls along a trend which links the field of keratophyres *sensu stricto* which that of orthokeratophyres (Schermerhorn, 1973).

The Paimpol spilites This formation crops out as an E–W belt parallel to the Trégier keratophyres and lies conformably above them (see Fig. 11). The thickness of the formation is of the order 1000–1500 m.

Within the formation are included many different rock types which can be distinguished by their

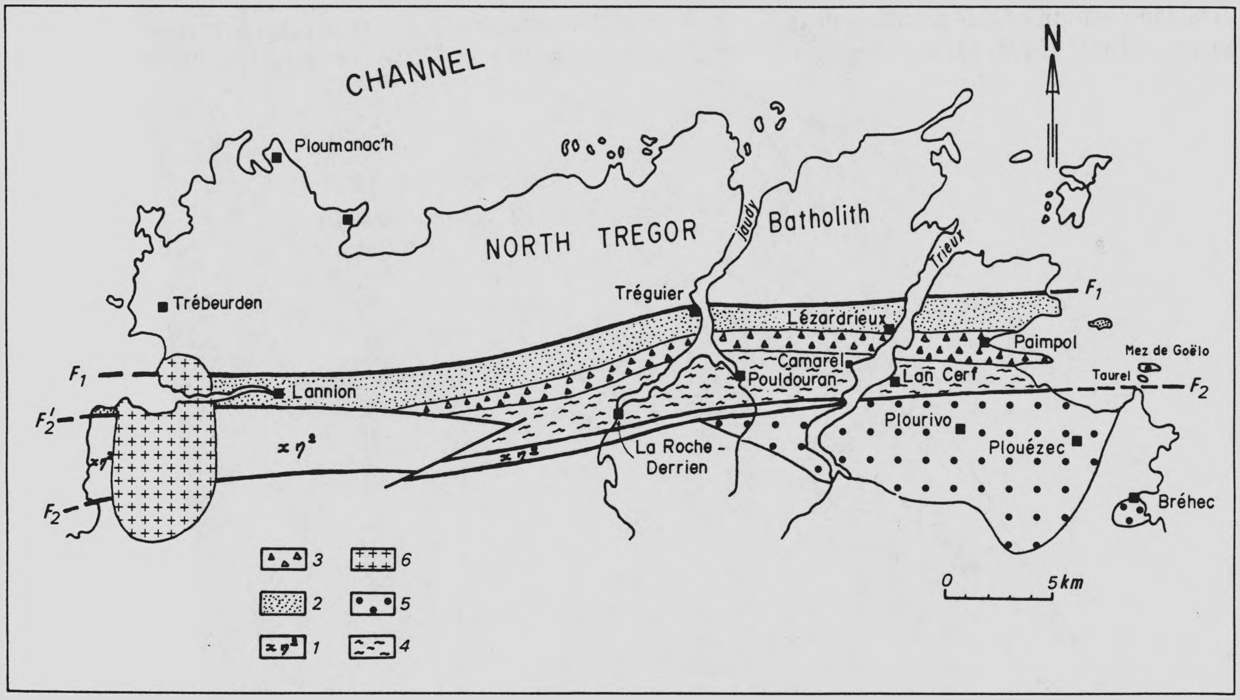

Fig. 11. Outcrop map of formations occurring within the southern sub-area of the Trégor. 1 — Plestin epidiorites (or l'Armorique–Trédrez series = côte de Trédrez formation; (?) Lower Brioverian); 2 — The Tréguier Keratophyres; 3 — The Paimpol Spilites; 4 — Roche-Derrien sediments (= Binic series; Upper Brioverian); 5 — Bréhec–Plouézec–Plourivo Red Beds (? Cambro-Ordovician); 6 — Trédrez Granite (Hercynian). F_1: Tréguier–Lézardrieux fault; F_2: Trégorrois fault (in Auvray, 1979)

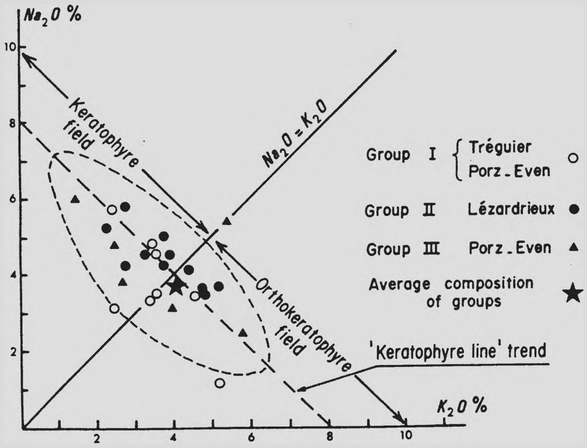

Fig. 12. Compositions of Tréguier keratophyres plotted on a Na_2O vs K_2O diagram (Battey, 1965) showing scattering about the 'keratophyre line' trend (in Auvray, 1979)

characteristic textures and structures. There are four main groups of rock types:

—Massive lava units with doleritic textures

—Pillow-lavas with microlitic, sometimes porphyritic, texture and highly vesiculated. Pillows are generally less than 1 m in size

—Brecciated lavas in which microlitic/porphyritic lava fragments of yellow–violet colour are embedded in a green groundmass also of microlitic/porphyritic texture

—Pyroclastics (tuffs, tuffites, volcanic breccias, etc.) are composed of many different kinds of fragments (crystals and whole rocks) set in a very fine-grained matrix.

These different rock types are interbedded with each other as 1–10 m thick members which all present a characteristic greenish colouration and typical spilitic mineral parageneses. The most commonly observed paragenesis is: albite, chlorite, epidote group minerals, quartz, and opaque phases. These essential minerals may vary in abundance from one rock type to another and are often accompanied by accessory calcite, sphene, leucoxene, actinolite, and sericite. Clinopyroxene is a very rare constituent, occurring only in certain massive lavas with plagioclases of basic composition (An_{55}). Hornblende has also been observed, although it is also rare. In addition, red jasper (hematite-bearing micro-quartz or jaspery chert) is often present in the vacuoles of pillow cores and sometimes in the matrix between pillows. The occurrence of this jasper is a very distinctive feature of the Paimpol spilites.

Tables 3, 4, and 5 show the overall basic composition of the different rock types discussed. All the same, it can be seen that clinopyroxene-bearing lavas with basic plagioclase have compositions most similar to basalt whereas other lavas show a more spilitic character (high Na_2O, low CaO contents). Morever, it has been demonstrated (Auvray, 1979) that most of the massive lavas are chemically very similar to 'high alumina basalts' (in particular high percentage of Al_2O_3: columns I and II, Table 3).

If we now consider all rocks belonging to the spilite–keratophyre association in the southern Trégor Massif, it is apparent that they mostly fall into the field of calc-alkaline magma series as shown in Figs. 13 and 14. A detailed geochemical study of the spilite-keratophyre association in the Trégor has led to the identification of two possible primary magmas from which the series were derived. The

Table 2. Chemical compositions of the 'Keratophyres de Tréguier': the SiO_2 contents represent minimum and maximum values (after Auvray, 1979)

SiO_2	58.79	69.39
Al_2O_3	17.32	14.38
Fe_2O_3*	6.56	3.66
MnO	0.54	0.07
MgO	3.15	1.13
CaO	2.78	1.07
Na_2O	4.46	4.06
K_2O	2.82	3.63
TiO_2	0.67	0.45
P_2O_5	0.17	0.04
$PF_{1000°}$	2.30	1.27
$PF_{110°}$	0.19	0.11

Table 3. Chemical compositions of the 'Spilites de Paimpol': I mean value (n = 9) for massive lavas with Cpx; II mean value (n = 8) for massive lavas without Cpx; III and IV examples of pillow-lava compositions (after Auvray, 1979)

	I	II	III	IV
SiO_2	48.08	49.56	47.85	51.62
Al_2O_3	17.39	19.26	17.49	15.98
Fe_2O_3*	9.34	8.99	10.14	7.72
MnO	0.15	0.13	0.23	0.13
MgO	8.59	6.36	8.70	9.86
CaO	8.41	7.09	11.40	5.18
Na_2O	2.50	3.57	1.96	4.96
K_2O	0.64	0.33	0.53	0.13
TiO_2O	0.84	0.93	0.74	0.77
$PF_{1000°}$	3.18	3.35	1.50	2.67

Table 4. Chemical compositions of the brecciated lavas included in the 'Spilite de Paimpol' formation (after Auvray, 1979)

SiO_2	64.12	50.79	51.40	55.21	57.54	49.98
Al_2O_3	17.00	19.70	19.75	19.70	19.06	17.71
Fe_2O_3	5.66	7.65	9.24	10.08	9.35	9.35
MnO	0.06	0.09	0.10	0.08	0.04	0.13
MgO	1.61	6.18	5.72	5.34	3.91	5.70
CaO	1.61	2.60	3.22	1.23	0.50	9.98
Na_2O	7.64	7.42	4.55	2.47	4.82	2.19
K_2O	0.12	0.26	0.16	1.60	0.66	0.03
TiO_2	0.70	0.75	0.68	0.68	0.90	0.82
P_2O_5	—	—	—	—	—	—
$PF_{1000°}$	1.51	3.92	3.87	4.58	3.45	3.91
$PF_{1000°}$	0.47	0.72	0.48	0.65	0.26	0.41
Total	100.50	100.08	99.17	101.62	100.49	99.41

Table 5. Chemical composition of pyroclastic rocks (breccias, tuffs, schalsteins) included in the 'Spilites de Paimpol' formation (after Auvray, 1979)

	Breccias		Tuffs		Schalsteins					
SiO_2	68.60	62.27	47.24	59.25	40.86	41.85	44.37	40.19	39.56	40.36
Al_2O_3	15.20	17.73	19.38	17.32	14.98	14.96	13.60	16.37	9.85	16.25
Fe_2O_3	4.43	4.70	9.73	6.44	5.83	5.95	7.78	7.12	4.91	3.57
MnO	0.08	0.08	0.14	0.06	0.10	0.10	0.11	0.11	0.17	0.11
MgO	2.11	2.50	8.42	5.83	4.12	4.37	4.38	3.77	2.15	2.09
CaO	0.30	2.11	7.08	3.51	14.75	13.80	12.60	14.12	19.88	17.23
Na_2O	5.93	4.51	2.08	3.03	2.91	3.32	1.47	1.76	2.75	2.34
K_2O	0.94	2.37	0.26	0.74	1.93	1.67	0.77	0.92	0.11	1.21
TiO_2	0.46	0.54	0.97	0.74	0.61	0.68	0.58	0.77	0.53	0.94
P_2O_5	—	—	—	—	—	—	—	—	—	—
$PF_{1000°}$	1.83	2.29	4.52	3.39	12.98	12.42	13.34	14.80	17.97	14.55
$PF_{110°}$	0.26	0.21	0.17	0.08	0.28	0.33	0.47	0.16	0.23	0.35
Total	99.94	99.31	99.99	100.39	99.35	99.45	99.47	100.09	98.11	99.00

first primary magma was of rhyodacitic composition and can be considered as the parent liquid for the keratophyres. The other primary magma was basaltic, and has given rise to the spilites. This two-magma hypothesis takes best account of the relative volumes and field relations of the volcanic formations involved (Auvray, 1979).

The Roche-Derrien sediments There is a rapid but continuous transition from the top of the Paimpol spilite formation, where intercalations of sediments become more and more abundant, into the base of a series of sediments that represent the youngest Upper Brioverian strata of southern Trégor (see Fig. 11). The Roche-Derrien Formation is up to 2500-3000 m thick, and is composed for the most part of grey sandstones, greenish-grey greywackes and dark-grey to black siltstones; quartzite members are rare and thin, limestones are even more uncommon. Sandstone and siltstone bed thicknesses vary from several centimetres to several metres, with alternations of beds on different scales in different parts of the outcrop area.

The detrital clastic component of these rocks is made up of quartz, phyllosilicates (chlorite, muscovite, and biotite), feldspars (orthoclase, microcline and plagioclase), epidotes, sphene, opaques, zircon, apatite, and lithic fragments (mostly spilite). The matrix cementing the clastic material is quartzo-phyllitic in nature and always very abundant. The petrographic character of these rocks, taken with the angular, ill-sorted and volcanoclastic (feldspar, mica, and lithic fragments) nature of their detrital components, reflects an immature sedimentary regime (rapid transport) with deposition on the continental shelf. Frequently observed sedimentary structures, such as loading and cross-bedding, also indicate the rapid deposition of immature sediments.

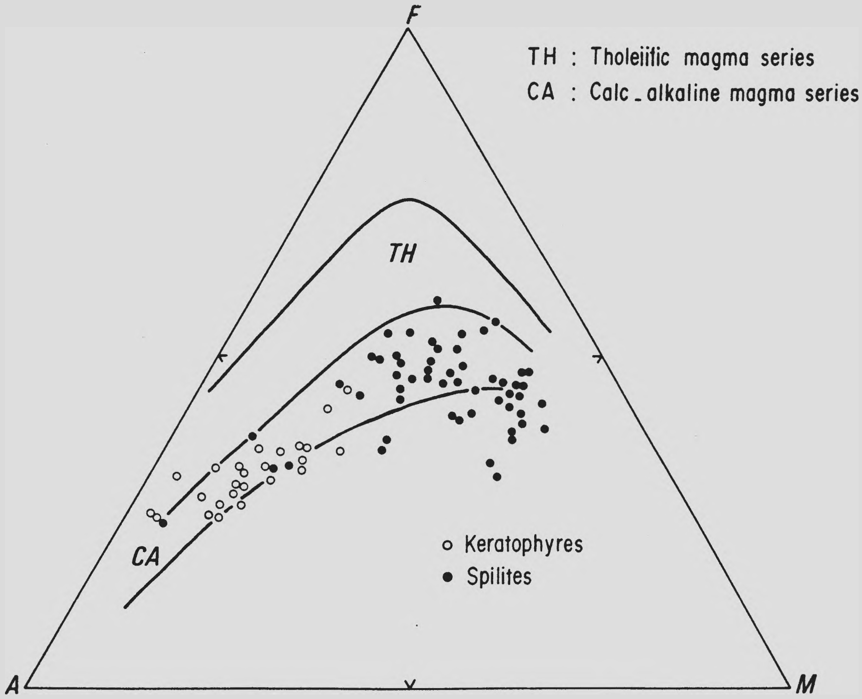

Fig. 13. Compositions of South Trégor volcanics plotted on an AFM diagram show a calc-alkaline magmatic series (in Auvray, 1979)

The Roche-Derrien sediments are very similar in many respects to the Binic series, situated a little further south, which is considered as the stratotype of the Upper Brioverian in this region (Cogné, 1962, 1965, 1974).

D—Gabbro-dioritic intrusives, Mancellian-type

The abundance of these intrusions towards the east and south (Saint-Brieuc region and the Mancellian domain) is in striking contrast with their scarcity in the Trégor. Here, the Mancellian-type intrusions are represented only by rare isolated stocks a few tens of metres across in the eastern half of the Massif (see Fig. 15).

In the absence of precise geochronological dating results, field relations place these intrusions after the Roche-Derrien sediments (which they intrude) and before the eruption of the Lézardrieux ignimbrites (dated at 550 Ma, see section below) which are stratigraphically above.

The most typical facies of this intrusive suite (as observed at Kéralain, see Fig. 15) corresponds to a coarse grained rock rich in hornblende (up to 60 per cent of the mode) and plagioclase (An_{35-40}). Other minerals are accessory, either primary, as in the case of chlorite, allanite, quartz, opaques, apatite, and orthoclase, or as alteration products such as epidote, chlorite, calcite, actinolite, leucoxene, sericite, and muscovite. Certain localities present a more leucrocratic facies with biotite (which can exceed hornblende in modal abundance) and clinopyroxene (augite).

Aplitic and pegmatitic (cm-scale amphiboles) veins are associated with these small granite stocks.

Table 6 gives two chemical analyses of this type of rock, whose basic composition is due to the abundance of amphibole. Such rocks probably represent cumulates from a dioritic magma (Auvray, 1979).

E—End-Precambrian alkali-granite and rhyolite suite

This highly silicic magmatic episode is well represented in the Trégor Massif, but is also known elsewhere in the northern part of the Armorican Massif (Jersey and St Germain-de-Gaillard in the Cotentin; Boyer, 1970, 1972, 1974). Volcanic/intrusive activity appears to have occurred at about the time of the Precambrian–Cambrian boundary (Auvray, 1982; Odin, 1982; Odin and Gale, 1982). In Normandy, these volcanics are immediately overlain

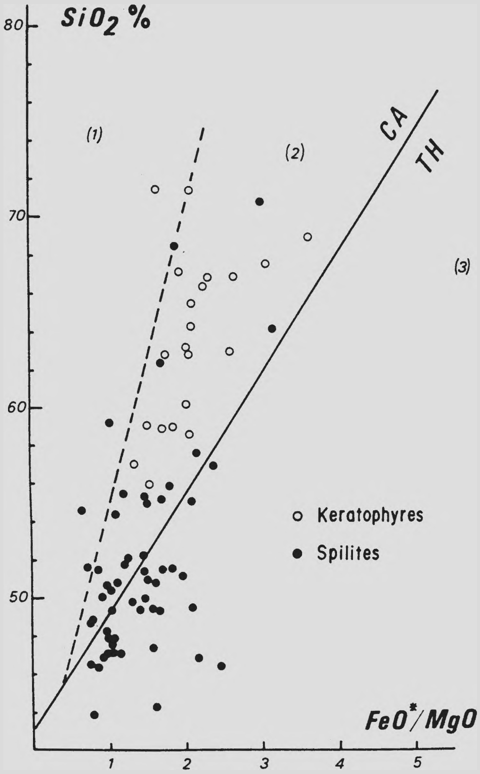

Fig. 14. Compositions of South Trégor volcanics plotted on major element variation diagrams (Miyashiro, 1975); same symbols as in Fig. 13 (in Auvray, 1979)

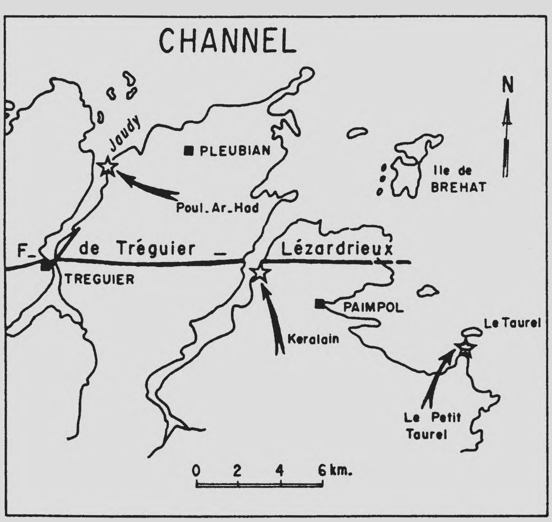

Fig. 15. Sketch map to show outcrops of gabbro-dioritic stocks (Mancellian-type plutons) (in Auvray, 1979)

by basal Archaeocyathid-bearing limestones which make up the lowest part of the Cambrian in this region (Dore, 1969).

In the Trégor, end-Precambrian magmatism is recognized under three different types of occurrence (see Fig. 16): granites, mcirogranites, and rhyolitic ignimbrites.

The age of this magmatism is well dated, yielding an age around 550 Ma (Auvray, 1975; Vidal, 1976; Auvray, 1979).

The rocks discussed here, whatever their exact type, share a number of common characteristics:

—Violet to pink colouration

—Great abundance of quartz and feldspar (more or less perthitic orthoclase and albite) which together make up more than 90 per cent of the rock.

—Biotite is the most important dark mineral present (hornblende can be found in the Porz-Scarff granite, but always at less than 1 per cent of the mode).

—The accessory mineral assemblage is observed in variable proportions according to type, but is always the following: opaque minerals, apatite, zircon, and muscovite–sericite; in addition, extrusive types include allanite and sphene as accessories.

In these highly leucocratic rock types, it is the texture which is most variable. Granites have a medium-grain sized granular texture, sometimes fine grained or even aplitic (in the marginal zone of plutons). Micrograntes have a fine, granular texture becoming coarsely porphyritic at the centre of veins (phenocrysts up to 1 cm in size) and aphanitic towards the margins (? chilled); granophyres are sometimes developed where the mesostasis of the micrograntes is rich in a micrographic intergrowth of quartz and alkali feldspar. Finally, the acid volcanics show very variable textures ranging from fluidal through spherulitic/perlitic to tuffaceous and brecciated. Some horizons contain good examples of dark-coloured 'fiamme' with typical axiolitic texture, and also broken glass shards giving the characteristic streaky texture of ignimbrites.

Chemically speaking (see Table 7), all the rocks in this suite are highly silicic and alkali-rich, with total alkali contents ($Na_2O + K_2O$) between 8 and 9 per cent. K_2O/Na_2O ratios indicate that the alkalic rhyolites are relatively more potassic, on average, than the alkali-granites. Within the alkali-rhyolite group, however, relative potash enrichment is extremely variable and erratic.

Table 6. Chemical compositions of Keralain-type diorite (after Auvray, 1979)

SiO_2	46.03	46.54
Al_2O_3	16.01	13.33
Fe_2O_3*	15.00	10.38
MnO	0.16	0.17
MgO	6.10	11.80
CaO	9.59	10.94
Na_2O	1.74	2.01
K_2O	0.78	1.19
P_2O_5	0.43	0.22
$PF_{1000°}$	3.87	2.14

Table 7. Chemical compositions of the three types of magmatic rocks characteristic of the Late Precambrian in the Trégor massif: (1) mean composition of the Porz-Scarff granite (n = 8); (2) mean composition of the Loguivy microgranite dykes (n = 10); (3) mean composition of the Lézardrieux ignimbrite volcanics (n = 17) (after Auvray, 1975, 1979)

	1	2	3
SiO_2	70.51	72.97	74.40
Al_2O_3	14.30	14.09	13.69
Fe_2O_3*	3.07	2.02	1.53
MnO	0.06	0.04	0.01
MgO	0.21	0.27	0.18
CaO	1.41	0.24	0.06
Na_2O	4.75	4.71	3.32
K_2O	3.62	4.00	5.31
TiO_2	0.20	0.30	0.17
$PF_{1000°}$	0.76	0.60	0.71
$PF_{110°}$	0.23	0.12	0.08

With this phase of alkali-rich silicic magmatism, the Precambrian geological evolution of the Domnonean domain comes to an end.

Conclusion and Interpretations

A compilation of all data obtained on the Trégor Massif enables us to draw up the sequence of geological events summarized in Figs. 2 and 3. The main points that can be concluded from this evolution are as follows:

— No geological event has been dated, or can be shown to have occurred, in the time interval from about 1800 Ma to 650 Ma ago. This would suggest there has been no event of Grenvillian age (*ca.* 1000 Ma old) in this part of the Armorican Massif; Mid-Proterozoic events, so well developed around the Laurasian continent, appear to be absent in this area.

— Only the Cadomian I phase of folding is seen to be developed during Brioverian times in the Trégor, as also inferred in other massifs of the Domnonean domain (e.g. Penthièvre Massif, see Fig. 1). The Cadomian II phase corresponds, in fact, to only rather gentle folding and very low grade metamorphism.

— During Palaeozoic times, the Trégor Massif acted as an uplifted cratonic block upon which no deposition of sediments occurred. Sedimentary deposits appear only in tectonic troughs bordering the Massif, as is the case for the Plouezec–Plourivo–Bréhec Red Beds.

Hercynian deformation is essentially brittle in style and brings about the reactivation of major E–W faults that originated during a late phase of the Cadomian orogeny (Trégorrois faults, Tréguier-Lézardrieux fault). Localized folding and fracture cleavage is thus seen near these E–W faults in formations affected by Hercynian reactivation (e.g. Roche-Derrien sediments). Late stage N–S faults are seen to cut the E–W faults, but are of lesser importance.

Thus, the Trégor Massif, fragment of the Domnonean block, can be considered to have completed most of its geological development before Palaeozoic times. From this point of view, the Trégor is analogous to the Mancellian domain but is in sharp contrast with regions further to the south (Central Armorican domain, Cornouaille Anticlinal domain, Ligerian domain and the Vendée) which show an essentially Palaeozoic geological evolution.

A geodynamic model has been proposed to account for the development of the North Brittany area during the Brioverian (Auvray, 1979). In this model, the conditions necessary for the proposed subduction hypothesis are as follows (see Fig. 17):

— The existence of continental crust in the area during the Brioverian: evidence from basement relicts, dated at 2000–1800 Ma, is found along the northern limit of the Armorican massif (Adams, 1967; Vidal, 1976; Calvez and Vidal, 1978; Auvray, Charlot, and Vidal, 1980; Vidal *et al.*, 1981).

— The existence of ocean floor: an important basic/ultrabasic body has been detected at depth under the middle of the English Channel (Lefort, 1975). This body, probably an ophiolite, is elongated NE–SW parallel to the margin of a belt of old basement outcrops (see Fig. 17) and thus may correspond to an ancient ocean (Channel Ocean). Due to later Hercynian compression, the only present-day trace of such a Channel Ocean is in the form of a cryptic suture (Lefort, 1975).

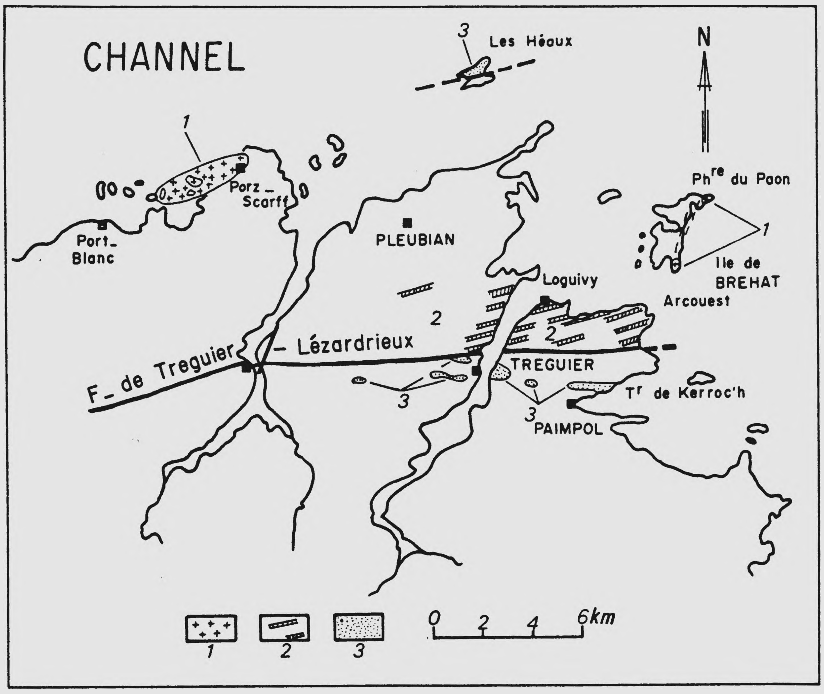

Fig. 16. Sketch map to show outcrops of various rocks belonging to the end-Precambrian alkali-granite and rhyolite suite. 1—Alkali-granites of Porz-Scarff and Le Paon; 2—Loguivy microgranites; 3—Lézardrieux rhyolitic ignimbrites (in Auvray, 1979)

The Cadomian orogeny is thus interpreted as the result of closing and subduction of the Channel Sea under the North Brittany continent (similar mechanism to that proposed by Wright, 1977 and Cogné and Wright, 1980 for the Celtic orogeny situated further north); the Channel Ocean subduction zone strikes NE–SW and dips towards the southeast (see Fig. 17).

The various stages in the history of this subduction are given below:

—Opening of the Channel Sea begins after the Grenvillian Orogeny around (?) 900–800 Ma ago.

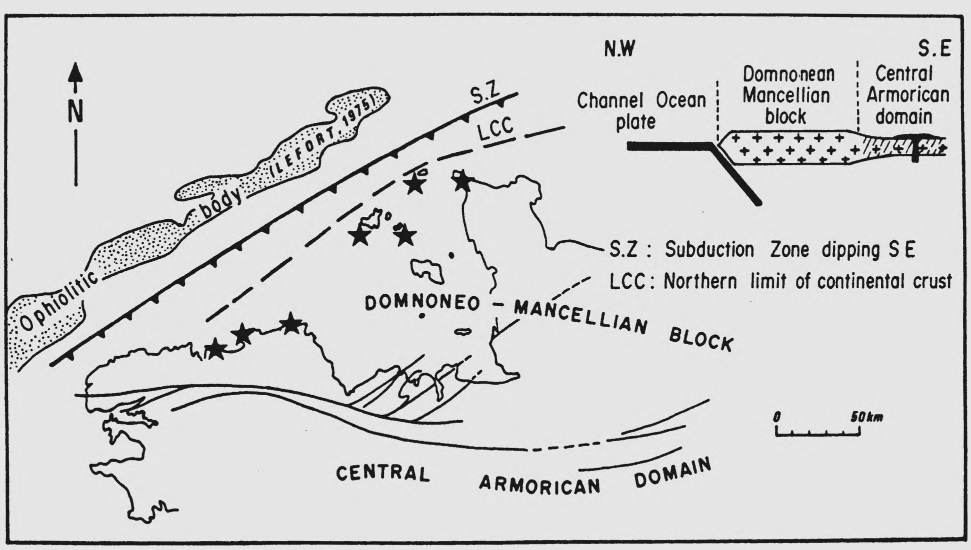

Fig. 17. Areas of ocean floor and continental crust as inferred during latest Precambrian times in the northern part of the Armorican Massif. Schematic cross-section to show position of plates during subduction. Stars indicate outcrops of known Lower Proterozoic basement (in Auvray, 1979)

—Channel Sea begins to close about (?) 750–700 Ma ago and the oceanic plate starts to be subducted under the North Brittany crustal segment. This leads to the formation of the volcanic and sedimentary series belonging to the lower Brioverian (e.g. the Lanvollon Formation further south and the l'Armorique–Trédez series in the western Trégor). However, the character and age of these volcanics await further clarification so this stage of geodynamic evolution must remain hypothetical.

—Between 650 and 550 Ma ago, subduction is at its height, with the associated generation of calc-alkaline magma types (major plutonic activity and volcanism). Only at the latest stages do magmas take on a highly silicic, alkali-rich character with the eruption of ignimbrites (e.g. Lézardrieux ignimbrites). Subduction-related phenomena not only affect the Domnonean domain but are also important in the Mancellian domain where, alongside magmatic activity, there is the development of a low-pressure metamorphic belt (Abukuma-type sequence observed in the Saint-Malo migmatite gneiss dome; Brun, 1975; Martin, 1977; Peucat, 1982).

Throughout these magmatic and metamorphic episodes, the Domnonean–Mancellian block was thus an active margin to the Channel Sea. The diagnostic features of an ancient subduction are still recognizable today.

—Behind the active margin, to the south, distension tectonics brings about crustal thinning which may even lead to the development of fracture-induced volcanic activity (see Fig. 18). In this way, the Central Armorican sedimentary trough came into being, with almost continuous sedimentation from the upper Brioverian to the Carboniferous. Also, the basic/ultrabasic complex of Belle-Isle-en-Terre (dated at 603 Ma) can be explained in terms of an ophiolite-like origin in a back-arc basin environment (Hirbec, 1979; Peucat *et al.*, 1981). The major lines of weakness in the crust were already in existence at this time (e.g. North Armorican shear zone; Chauris, 1969; Gapais and Le Corre, 1980) and were reactivated later during the Hercynian orogeny.

—At the end of subduction (550 Ma ago), vertical faulting develops which leads to the formation of horst- and graben-like structures. This facilitates the ascent of the latest-formed magmas and accounts for the accumulation of Palaeozoic sediments in tectonic troughs; Red Beds around the Normandy–Brittany Gulf are the earliest evidence for this 'molasse', occurring near the Cambro-Ordovician boundary and having an age of about 480 Ma (Auvray *et al.*, 1980).

There appears to be an absence of any important phase of folding (compressive tectonics) to mark the end of the Proterozoic. This would imply that closing of the Channel Sea was not complete at this

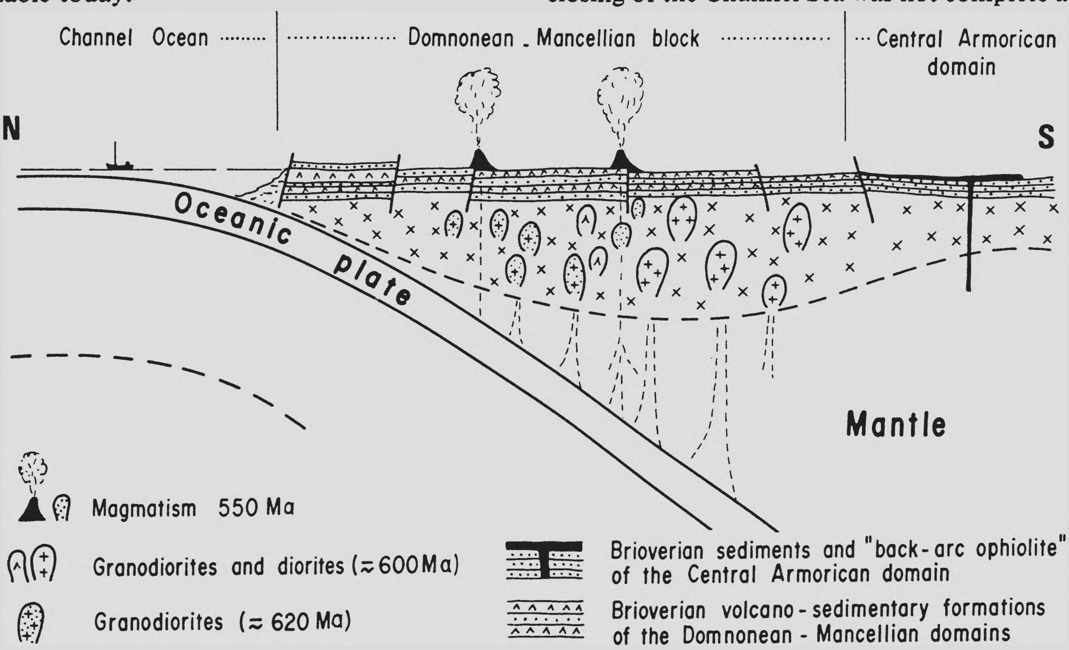

Fig. 18. Diagrammatic cross-section to show operation of subduction at the end of Proterozoic times at the northern margin of the 'Armorican Massif' (in Auvray, 1979)

time (lack of continent–continent collision). The cryptic nature of the suture defined by a 'basic body' now under the Channel (Lefort, 1975, 1977) has arisen from later phenomena related to Hercynian compressive tectonics. The ophiolitic complex of the Lizard (S. Cornwall, England) could represent a fragment of the Channel Sea floor that has been thrust over autochthonous Palaeozoic formations (Auvray, 1979).

The outstanding characteristic of this northern part of the Armorican massif, surrounded on all sides by Variscan orogenic effects, is that recognizable features of primary origin have been preserved almost intact. Thus, the area provides a valuable element in the reconstruction of Precambrian geological events that mark the birth of continental crust underlying a large part of the Hercynian fold belt of Western Europe.

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1.2 PROBLEM OF THE LOWER BRIOVERIAN IN THE CONTEXT OF A TWO-PHASE CADOMIAN OROGENIC CYCLE: THE PRECAMBRIAN OF THE PENTHIEVRE MASSIF AND ITS ADJOINING MANCELLIAN BOUNDARY

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A Brioverian succession involving basic volcanics and pelites with black cherts (phthanites) was first proposed in the Baie de Saint-Brieuc by Barrois *et al.* (1939), who correlated the Erquy beds with volcanic formations at Lanvollon below the Lamballe pelites and cherts. Later work by Graindor (1957) established a stratigraphic succession which led to the recognition, in the northeastern part of the Armorican massif, of a lower-middle Brioverian Group followed by the Upper Brioverian. These two groups are also thought to be separated by orogenic events of an ill-defined nature which are responsible for the presence of sedimentary and crystalline clastic material (derived from the Lower Brioverian) at the base of the Upper Brioverian in Normandy.

As originally defined in Normandy, this Brioverian succession included a 'middle' section of sedimentary strata lying stratigraphically above volcanic formations of lower Brioverian age. Since the middle and lower parts of this succession have suffered similar tectonometamorphic events, it has been proposed to place them together in the same group—i.e. Lower Brioverian (Cogné, 1970 and 1974; Dupret, this volume). After the different parts of the Brioverian succession were subdivided into series in Normandy (Graindor, 1957), other workers (Cogné, 1962; Jeannette, 1972) extended the correlation into Brittany, where the following succession (Cogné *et al.*, 1980) has emerged for the Domnonean and Mancellian domains taken together: